Analogue Input Calibration of the ATLAS Level-1 Calorimeter Trigger – TWEPP-09

J.D. Morris[a,b]

[a] On behalf of the ATLAS TDAQ Collaboration [1]
[b] Queen Mary University of London, Mile End Road, London, E1 4NS, UK

john.morris@cern.ch

Abstract

The ATLAS Level-1 Calorimeter Trigger is a hardware-based pipelined system using custom electronics which identifies, within a fixed latency of 2.5 μs, highly energetic objects resulting from proton-proton interactions at the LHC. It is composed of three main sub-systems. The PreProcessor system first conditions and digitizes approximately 7200 pre-summed analogue calorimeter signals at the bunch-crossing rate of 40 MHz, and identifies the specific bunch-crossing of the interaction using a digital filtering technique. Pedestal subtraction and noise suppression are applied, and final calibrated digitized transverse energies are transmitted in parallel to the two subsequent processor systems, which perform the algorithms and calculate the variables the trigger menu is tested against. Several channel-dependent parameters require setting in the PreProcessor system to provide these digital signals which are aligned in time and properly calibrated. The different techniques which are used to derive these parameters are described, along with the quality tests of the analogue input signals and the status of the energy calibration.

I. The ATLAS Level-1 Calorimeter

A. The ATLAS Trigger

The ATLAS trigger system consists of three separate components. The task of the ATLAS trigger is to reduce the event rate from 40 MHz to 200 Hz. A schematic of the ATLAS trigger can be seen in Figure 1.

The Level-1 trigger consists of a calorimeter trigger which operates on reduced information from the calorimeters and a muon trigger that works on special trigger chambers within the muon detectors. The Level-1 system has a requirement that the latency be less than 2.5 μs. The Level-1 calorimeter and muon triggers have two outputs, the real time data path which transmits information on the multiplicity of each trigger menu item to the central trigger processor (CTP). The CTP generates a Level-1 accept or reject decision, deciding if the event is of interest or not. The other output is sent to the Level-2 trigger in the form of regions of interest (RoIs), which are small energetic regions of η and ϕ that are used as the input seeds for the Level-2 algorithms.

The Level-2 trigger and HLT is software based comprised of approximately 500 CPUs taking the Level-1 RoIs as its input. The Level-2 trigger has access to the full granularity of the ATLAS detector and has a requirement that the latency be, on average, less than 40 ms.

The Event filter, or Level-3, is a software trigger comprised of approximately 1600 CPUs. The event filter has access to the full event information, calibration constants and offline algorithms.

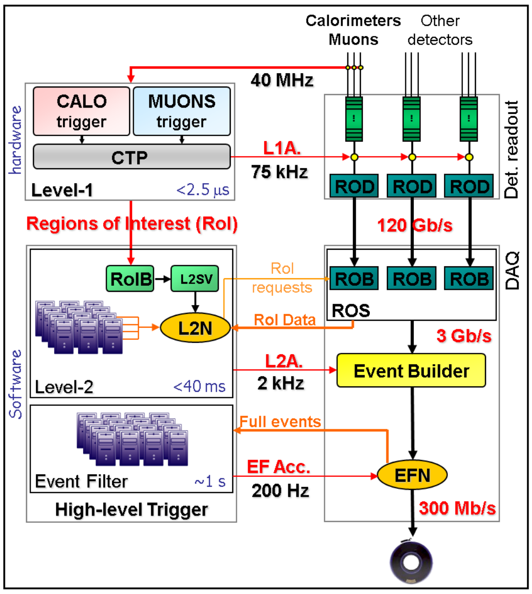

Figure 1: The ATLAS trigger system.

B. The Level-1 Calorimeter Trigger

The ATLAS Level-1 calorimeter trigger (L1Calo) is fully described elsewhere [2]. L1Calo is a 1 μs fixed latency, pipelined, hardware based system which uses custom electronics. The additional 1.5 μs comes from cable delays. L1Calo consists of nearly 300 VME modules of 10 different types housed in 17 crates. L1Calo is located entirely off detector in the service cavern USA15.

Around 250,000 calorimeter cells are summed to 7168 L1Calo trigger towers. The granularity of L1Calo is described in Table B..

Position	$\Delta\eta$ x $\Delta\phi$
$\|\eta\| < 2.5$	0.1 x 0.1
$2.5 < \|\eta\| < 3.1$	0.2 x 0.2
$3.1 < \|\eta\| < 3.2$	0.1 x 0.2
$3.2 < \|\eta\| < 4.9$	0.4 x 0.4125

Table 1: Granularity of L1Calo trigger towers/

L1Calo has three processor types. The PreProcessor (PPr) digitizes the analogue calorimeter pulses, performs bunch-crossing identification and converts ADC counts to energy. The Cluster Processor (CP) identifies electrons, photons and single hadrons. The Jet/Energy-sum processor (JEP) does jet finding and energy sums.

C. The PreProcessor (PPr)

The calorimeter pulses are obtained through the receiver system which provides input signal conditioning via variable gain amplification. Due to the different hardware configurations of the different calorimeters, some signals are transmitted to L1Calo proportional to E and some proportional to E_{T}. The gain on individual receivers is set such that, if necessary, a $\sin(\theta)$ correction from $E \rightarrow E_{\mathrm{T}}$ is performed. The calorimeter pulse is sampled at 40 MHz by 10-bit flash-ADC. The calorimeter pulse is sampled over five bunch-crossings with the pedestal set at 32 ADC counts.

Bunch-crossing identification is performed using a peak finder, which uses a special algorithm for saturated pulses. A finite impulse response (FIR) filter aids the peak finder by sharpening the signal and improving the signal to noise ratio. The final E_{T} is calculated using a look up table which removes the pedestal and provides noise suppression.

D. The Processors

Both the CP and JEP processors work on the E_{T} values provided by the PPr. Both processors use sliding window algorithms which provide local E_{T} maxima with multiple thresholds and isolation criteria. The CP uses a 0.1 x 0.1 granularity and operates in the $|\eta| < 2.5$ region, while the JEP uses a 0.2 x 0.2 granularity, sums the electromagnetic and hadronic layers of L1Calo and operates over the whole of the ATLAS $|\eta| < 4.9$ region.

II. Timing calibration

The precise timing of all L1Calo trigger towers is important for the identification of the correct bunch-crossing and also for the correct measurement of the deposited energy. The timing of L1Calo is critical, if the timing is wrong ATLAS will not record the correct event. In a physics event, the *pp* collisions take place at the interaction point and the time-of-flight of final state particles to the calorimeters is η dependent. When a signal is sent from the calorimeters to L1Calo transmission along the cables takes time. Due to the cabling of ATLAS, the length of time taken for a signal to travel from the calorimeters to L1Calo varies greatly and is both η and ϕ dependent.

L1Calo timing is calibrated in two ways. Coarse timing, in steps of 1 bunch-crossing (25 ns) allows identification of the correct bunch-crossing. Fine timing, in steps of 1 ns, allows L1Calo to sample the calorimeter pulse at its peak.

A. Coarse timing

The coarse timing of L1Calo is set by a FIFO, in steps of 25 ns. The timing is calibrated using repetitive calorimeter pulser runs, provided by the calorimeter calibration system. The analogue signals sent from the calorimeters are lined up in L1Calo by adjusting the FIFO settings.

The calorimeter calibration system provides pulser runs for each calorimeter partition, these consist of the Barrel and different end-caps. This allows for a common FIFO setting to be established for each partition and relative FIFO settings for all L1Calo channels within a partition. It is not possible to check the timing of one partition against another, so cosmic data is employed. Cosmic rays occasionally leave calorimeter deposits which span two calorimeter partitions, and the timing can be checked to line up the different partitions.

A priority for first beam will be to establish the correct coarse timing for L1Calo. Initial collision events will be triggered by a logical *AND* between the beam pickup system and L1Calo, allowing L1Calo to study the timing for every channel in which a signal is observed. The FIFO settings will be adjusted so that every L1Calo channel observes the peak of the calorimeter pulse in the correct bunch-crossing.

B. Fine timing

The fine timing of L1Calo is set by the PHOS4 chip, which varies the timing of each channel by 1 ns. Using the calorimeter calibration system, repetitive pulses are received by the L1Calo system. The PHOS4 setting of each channel is varied through all 25 settings and the signal shape is reconstructed and fit offline to determine the peak of the signal. This methodology allows the timing of each L1Calo channel to be set to 1 ns. Figure 2 shows the output of a PHOS4 scan for a typical L1Calo channel.

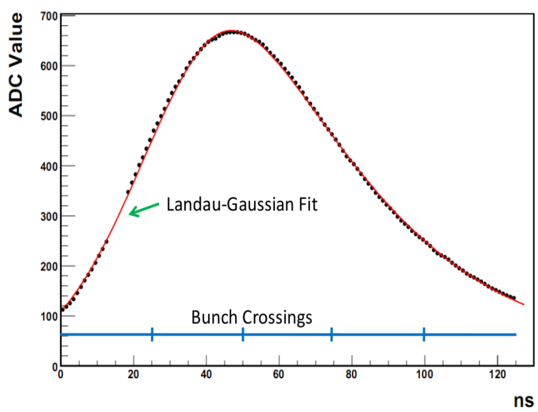

Figure 2: A PHOS4 scan. The amplitude of a calorimeter pulse measured over 125 ns. A Landau-Gaussian is fitted to the data to determine the peak position.

III. Internal calibration

L1Calo must be calibrated internally. This means that all channels should behave the same way. All channels should have the correct receiver gain setting and a similar pedestal. Bunch-crossing identification is optimized with internal finite impulse response (FIR) filter settings.

A. *Setting the pedestal*

L1Calo chooses to set the pedestal of each channel to $2^5 = 32$ ADC counts. As each L1Calo channel has a different response, a DAC scan is performed which determines the linear relationship between the DAC value and the ADC counts. The DAC scan shifts the analogue pulse into the sensitive voltage window of the ADC. Such a relationship can be seen in Figure 3 Each channel has a different slope and offset. When the pedestal is set the slope and offset values are used to set each pedestal close to 32 ADC counts.

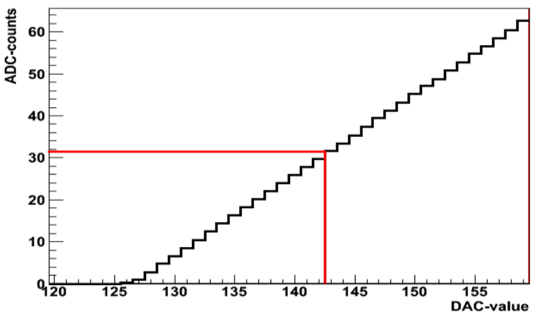

Figure 3: A DAC scan. The DAC value is varied to determine a linear relationship with the number of ADC counts. The slope and offset needed to set a pedestal of 32 ADC counts is determined.

B. *Checking the pedestal*

Once the pedestal of each channel has been set with a DAC scan, the value and width of each channel is checked with a pedestal run. This provides a check and ensures that L1Calo is setting the pedestal correctly. Shown in Figure 4 is the RMS of the pedestals of the electromagnetic section of L1Calo. The colour scale is in ADC counts, the pedestal width can be seen to decrease with increasing η, due to $\sin(\theta)$ attenuation.

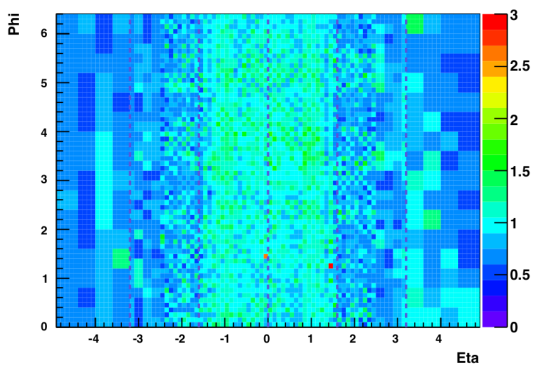

Figure 4: Pedestal RMS of the electromagnetic section of L1Calo.

C. *Finite Impulse Responce (FIR) Filter*

L1Calo makes use of Finite Impulse Responce (FIR) filters to improve bunch-crossing identification and to aid in noise suppression. The calorimeter signal pulses span many bunch-crossings and the FIR filters have the effect of sharpening the signal prior to bunch-crossing identification. An optimal performace is achieved when the filter coefficients match the pulse shapes. The FIR filter coefficients are individually settable for each L1Calo channel. A schematic of the FIR filter logic is shown in Figure 5.

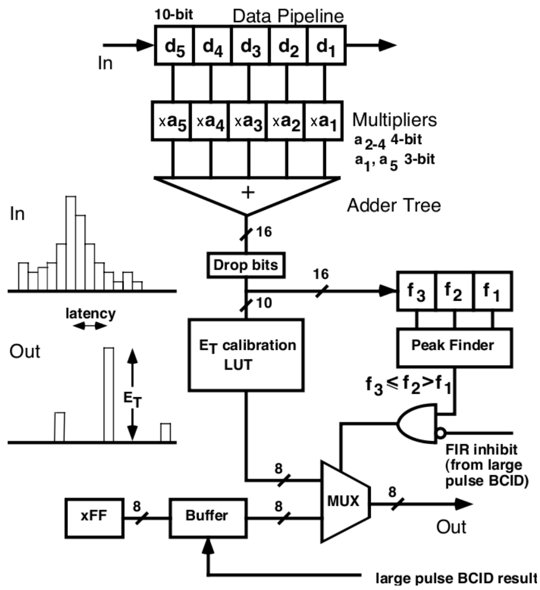

Figure 5: FIR filter logic. $d_{1,..,5}$ represent the input pulse and $a_{1,..,5}$ represent the FIR filter coefficients.

A Monte Carlo study of the effect of different sets of FIR filter coefficients has been performed. The efficiency of the bunch-crossing identification is defined as

$$\epsilon = \frac{\#\,\text{pulses with correct peak}}{\text{All pulses}} \tag{1}$$

Three different sets of FIR filter coefficients were used, and are shown in Figure 6. Set A, shown in stars, is just the peak finder with the filter in pass-through mode. Set B, the optimal FIR filter, shown in circles, has the FIR filter coefficients of each channel individually defined. Set C, shown in triangles, has the same FIR filter coefficients for all channels are derived from channels which sit in the region with the highest noise $(\eta = 0)$.

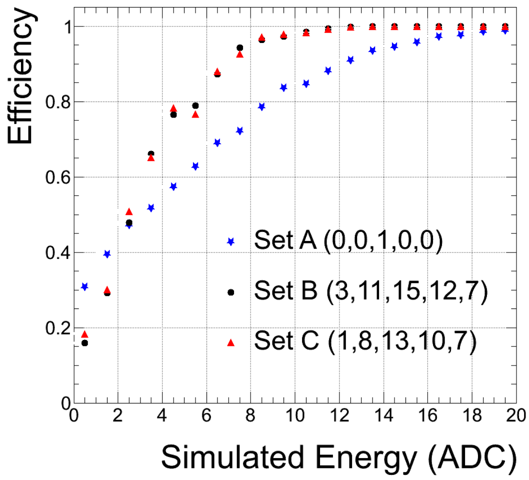

Figure 6: Monte Carlo bunch-crossing identification efficiency. 1 ADC count corresponds to approximately 250 MeV. Shown for 3 differtent FIR filter coefficient settings.

As shown in Figure 6, Set A shows the least efficiency, while Set B and Set C perform similarly. The L1Calo strategy for early collision data is to start with a relatively simple system and understand it before moving onto more complex environment settings. Therefore, based on Set C, FIR filter coefficients will be defined for the hadronic, electromagnetic and forward calorimeter regions.

IV. Energy calibration

The number of ADC counts measured by L1Calo does not immediately translate to an energy in MeV. This requires calibration, the goal is to calibrate the system so that 1 ADC count corresponds to 250 MeV on the electromagnetic scale.

The calorimeter calibration system provides pulser ramp runs where the pulses are provided in a sequence of different discrete amplitudes. Approximately 200 pulses per energy step are taken, this number can be changed if required. The energy given by the calorimeter is correlated with the energy measured by L1Calo and the energy ramp is fitted offline. The slope and offset of the fit are determined for each L1Calo channel. Shown in Figure 7 is the trigger tower energy, the calorimeter energy and the energy ramp. Each L1Calo channel is being tuned and the calibration constants are becoming increasingly stable.

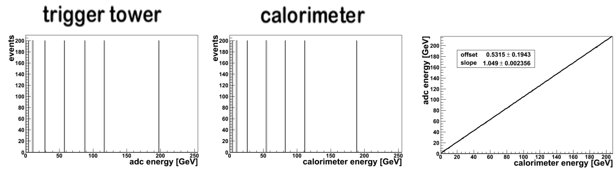

Figure 7: Calibration of L1Calo. Trigger tower energy(left), calorimeter energy(middle) and the correlation between the two(right).

V. Plans for first collisions

Once the LHC delivers collisions to the ATLAS detector, physics calibration will be a clear priority for L1Calo. Early events will be triggered by the beam pickup system, which detects when a bunch-crossing takes place. This will allow L1Calo to quickly determine the coarse and fine timing from physics events.

Offline analysis comparing reconstructed physics objects and L1Calo regions of interest will feed back into the overall calibration of L1Calo. The analysis of electrons and photons will enable L1Calo to determine the electromagnetic scale of the system.

Once L1Calo has been understood sufficiently, the plan is to increase the complexity of the calibration. L1Calo will increase the number of FIR filter coefficient settings if required. The hadronic scale will be determined and dead material corrections will be applied.

References

[1] The ATLAS Trigger/DAQ Autholist, version 3.0
ATL-DAQ-PUB-2009-007
CERN, Geneva, 2009
http://cdsweb.cern.ch/record/1207077

[2] R. Achenbach et al.,
The ATLAS Level-1 Calorimeter Trigger,
2008_JINST_3_P03001.
(ATL-DAQ-PUB-2008-001)
http://www.iop.org/EJ/abstract/1748-0221/3/03/P03001